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Computers and the Mechanics of Communication

Outline of a Vision from the Work of Petri and Holt

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Abstract. Computers have become an integral part of a vast range of coordination patterns among human activities which go far beyond mere calculation. The conceptual relevance of this new field of application of computers has been advocated by Carl Adam Petri (1926-2010) and Anatol W. Holt (1927-2010), two computer scientists best known for their contributions to the subject of *Petri nets*, a graphical formalism for describing the causal dependence of events in systems distributed in space. We outline some fundamental, mainly epistemological aspects of their vision of the computer as a "communication machine." [1]

1 Overview

One approach to the theoretical study of computation, that dates back to the early years of the discipline, has concentrated on the problem of synthesis of automata out of simple components, rather than on the closure properties of classes of computable functions. It is in this tradition that Carl Adam Petri (1926-2010) formulated a novel approach to automata theory that took seriously the physical limitations that such systems have to comply with, in particular upper bounds on the propagation speed of signals and on the density of storage of information. In Petri's 1962 PhD dissertation [26], these constraints were the guiding principles underlying the design of a class of asynchronous systems whose programming consists essentially in setting up communication rules among their parts in order to achieve coordination of behavior. The central questions here are relative to the causal relations among events: in particular, it is in this context that *concurrency* can find a general formulation as causal independence.

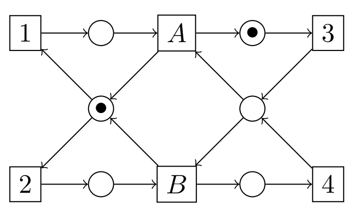
The ideas of Petri were pursued at an early stage, and partly in collaboration with him, by Anatol Wolf Holt (1927-2010), although he was less interested than Petri in the relations of these ideas to physics and mathematics, being primarily

[1] Appeared in: Arnold Beckmann, Victor Mitrana and Mariya Ivanova Soskova, *Evolving Computability - 11th Conference on Computability in Europe, CiE 2015, Bucharest, Romania, June 29–July 3, 2015*. Proceedings. Springer Lecture Notes in Computer Science 9136, pp. 3–12, Springer-Verlag 2015, doi: 10.1007/978-3-319-20028-6_1

concerned with their use in the specification and analysis of computer systems. By setting up a theoretical approach to computing based on classes of Petri nets (a name introduced by Holt himself), and by demonstrating the expressive power of the latter in application areas ranging from the design of hardware components to the analysis of legal systems [25], Petri and Holt outlined a vision of a computer as a "general medium for strictly organized information flow" [28], a "medium for the transmission of messages between persons" [5], providing a theoretical complement to the ideas of Licklider [24] on the computer as a communication device.

An essential sketch of the scientific biography of Anatol Holt may contribute to appreciate his place in the development of computing in the United States.[2] After earning degrees in mathematics from Harvard (1950) and MIT (1953), where he was employed at the Research Laboratory for Electronics of Robert Fano as a research assistant in information theory, Holt started his reflection on computers and their role as a UNIVAC programmer in Philadelphia, where he worked for Sperry Rand Corporation from 1952 to 1960 and where, with W.J. Turansky, designed and implemented the *Generalized Programming* system [4]. In 1955, Holt became Associate Director of the Univac Applications Research Center, established by himself and J.W. Mauchly. After getting a PhD in descriptive linguistics from University of Pennsylvania under Zellig Harris (1963), while at Massachusetts Computer Associates, a subsidiary of Applied Data Research, Holt led the ARPA supported Information System Theory Project (1964-68) [6] and subsequent projects until the end of the 1970s. These produced a large amount of theoretical and applied work on Petri nets, influencing in particular the research on asynchronous hardware and on data-flow computer architectures through relations with the Computation Structures Group led by J. B. Dennis at MIT, and contributing to spread the notions of concurrency, conflict and causality.[3]

As an example of the Petri net representation of these notions, we show the design of a two-stage asynchronous pipeline for bits, taken from an unpublished review from Holt's *Nachlass* dated November, 1976:



Here events 1 and 2 represent the input of a bit 0 or a bit 1, respectively, in the first stage of the pipeline, and similarly for events A and B. Conditions represent the states of each stage: empty, holding bit 0 and holding bit 1. The pairs of

[2] For a biography of Petri, see the recent book by Einar Smith [34].

[3] Extensive documentation on this work is now available at the page of the Defense Technical Information Center, `http://www.dtic.mil/dtic/index.html`, search for example for the strings "AD0704796", "ADA955303", "ADA047864".

events 1 and 3, and 2 and 3 are concurrent: both events of each pair are enabled to fire according to the rules for the token game on nets [22]. The events 1 and 2 are in conflict: both are enabled because their common precondition is marked, but only one of them can fire, thus disabling the other. One important feature of this model of a pipeline is the synchronization of a forward flow of tokens in the system, representing the bits, with a backward flow of tokens representing permits (or requests for data): this is essential to the design of safe asynchronous communication mechanisms.

As Director of the Computing Center of Boston University, Holt's interests focused more closely on the development of computer support for human organized activity and the related descriptive formalisms, like role/activity nets [12]. After an appointment at ITT as the leader of a Coordination Technology research group, in 1986 he founded and became Chief Technical Officer of Coordination Technology, working in particular on the development of new formalisms for coordination [17]. In 1991 he moved to Milano, Italy, where he continued his research on organized human activity interacting with researchers in the area of Computer Supported Cooperative Work at the Università di Milano and others interested in his ideas (like the present writer). The main outcome of this research was the book [19], soon followed by a shorter one which appeared in an Italian translation [20], and several papers on organized activity, in particular in relation to the novel approach to information suggested by his outlook [21], that he planned to investigate in a book of which several drafts survive. His last writing, as far as we know, has been an unpublished revision of the 1997 book, written in 2003.

The aim of this paper is to compose an introductory account of the vision of computer as a communication machine from the published and unpublished material by Petri and Holt, mainly focussing on the epistemological issues that underlie their endeavor rather than on the technical achievements.[4] After a short introduction to Holt's approach to systems as expression of organized human activities, we discuss its consequences on a systemic interpretation of the notion of *information* and outline two ways of looking at the interpretation of computers as communication machines: Holt's *communication mechanics* and Petri's *communication disciplines*. Finally, we comment on some mathematical aspects of the relations between discrete and continuous models of digital systems, motivated by communication mechanics and based on a topological interpretation of the primitive notions of Petri nets.

[4] Both Holt's *Nachlass*, that we are currently studying, and that of Petri, are preserved at the Deutsches Museum in Munich.

2 Computers, systems and communication

2.1 Communication mechanics

Through his acquaintance with Gregory Bateson and his family[5] Holt interacted with cyberneticians and systemically oriented thinkers[6] developing a loosely systemic attitude towards computing, whose main ideas can be gathered from his papers from the period 1968-80, for example [6, 7, 9–11, 13]. As an early illustration of Holt's interest in systemic notions, one of the concerns of the Information System Theory Project was the "analysis and description of data structures", where a data structure should not be thought of as "a static set of elements with interrelations" (ibid., p. 4), but rather should be identified with the basic operations made possible by that structure.[7] For example,

> we might consider beginning with a list of the elementary events which we suppose can occur involving a 1-dimensional array [. . .] Given this list of events we can now describe the constraints on their relative occurrences. [. . .] A set of mutually constrained events is what we call a *system* [6, pp. 4-6].

Examples of systems involve patterns of coordinated activity "such as the flow of traffic at a highway interchange, the operation of an elevator responding to calls on different floors, an iterative procedure for successively approximating the solution of a differential equation" (ibid., p. 9). In this perspective, systems are identified with the mechanical aspects of human organizations, expressed in rules whose function is to "establish certain relations of communication among a set of role players" [7]. Their investigation leads to *communication mechanics*,

> a theory about the mechanical aspects of communication – i.e., those aspects that have to do with the *rules*, insofar as these can be formalized, which define the relations among a set of communicating parts [. . .] We regard the words 'organization' and 'system' as referring to such bodies of rules [7].

Holt later developed communication mechanics into a theory of organized activity whose formalization instantiated the elements of the bipartite ontology of

[5] Holt's mother, Claire Holt, collaborated with Bateson and his wife, Margaret Mead, as an expert of Indonesian art, especially of Balinese dance, see [2] for a biography.

[6] This happened in at least one important context, the Wenner-Gren Conference on the Effects of Conscious Purpose on Human Adaptation held in Burg Wartenstein (Austria) in 1968, as evidenced by the proceedings edited by Bateson's daughter, Mary Catherine [1]. Holt was one of the main characters of that conference which included as participants Gregory Bateson, Barry Commoner, Warren McCulloch and Gordon Pask, among others.

[7] In this novel approach to the characterization of data structures we can see perhaps a first hint of techniques for data abstraction that would become a leading theme of programming language design in the next decade, culminating with the notion of (software) *object*.

Petri nets, made generically of *conditions* and *events*, first as *roles* and *activities* [12, 3] and, eventually, as *bodies* and *operations* [15, 17, 19]. Roles are the hallmark of organized activity: in the context of organized activities persons play *roles* and it is in such roles that they perform actions. By doing so, persons assume responsibilities that reflect organizational interests, becoming *actors*. As a machine cannot assume any responsibility for its actions, actions cannot be *performed* by machines: this remark lies at the heart of Holt's critique of the idea of artificial intelligence and, more generally, of the personification of computers [5]. In the system context, actions are units of *organizational time*: the time represented in calendars and planners and made up of lumps of human effort. Similarly, space enters this picture in the form of *organizational space*, for example files, cabinets, rooms or buildings. For all these examples,

> their *coordination-relevant structure* cannot be described in the language of physics. The description of this structure necessarily makes reference to *the manner of its use in the conduct of socially organized activity*, perhaps only by implication [18].

Organizational space has a topological structure whereby entities that interact directly are spatial neighbors, cfr. [12], an operational conception of topological relations which is distinctive of communication mechanics, as we shall see later.

2.2 Communication disciplines

Holt was concerned with a notion of information subsuming the multitude of ways informational phenomena enter the picture of human organizations as supported by computers:

> Information processing and information flow within a machine cannot be adequately engineered without the power to see it as integral to information processing and flow within an organization [13]
> "the user" is a community with a diversity of roles and interests all of which *concurrently* affect the use of the machine (or complex of machines) [. . .] At any one time the machine is not serving one man but is participating in the establishment of a relation between several men [. . .] a very different matter than the standard concept of a "computational problem" [8].

An initial attempt at a technical notion of information supporting the study of the causal relations among decisions in systems, was explored by Holt and Fred Commoner in their contribution to the Project Mac Woods Hole conference in June 1970, in the restricted setting where a system is represented by a state machine [22]. Information is input at states where a decision has to be taken as to which of several possible actions should be performed next; dually, information is output when several actions lead to the same state: namely the information needed to backtrack from that state.

Holt's systemic notion of information matches a notion of communication which does not reduce, as in Shannon's seminal work, to "reproducing at one point either exactly or approximately a message selected at another point" [33]. The reception via fax of a perfect reproduction of a $100 bill does not count as a successful money transfer. Holt's first attempt at a criticism of traditional communication theory in a technical context, [9], reveals the hidden *organizational* assumptions underlying Shannon's theory: in the systemic treatment, information is studied as a correlate of coordination or, more generally, of organized activity.

According to the new theory of communication, in any organized human activity the material aspects, including representation, are essential: this is a recurring theme through Holt's reflection, from the early formulations of communication mechanics witnessed by Mary Catherine Bateson at the Burg Wartenstein conference:

> Tolly went up to the board and wrote the number two in several ways, 2, II, ii, 2, a tiny two and a monstrous one [...]
> — There is a profound illusion that it is possible in a systematic sense to separate the representation from what is represented [...] it is a fundamental error [...] The symbol is nothing apart from its uses [1, pp. 156-57]

to a late list of popular assumptions running counter to the proper foundations of a theory of organized activity, quoted from an unpublished draft translated into Italian as [20]:

> The logic of a formal procedure (and therefore organized activity) is clearly separable from the physical means by which it is performed (and therefore separable from time/spatial considerations) [...] in the study of organized activity the opposite is assumed

The following table, extracted from [10, p. 166], summarizes the basic tenets of the systemic view of information by constrasting it with the conventional view:

Conventional	**Systemic**
Information is an imperishable good	Information has validity only within a given context
Information content and form are, in principle, factorable from one another	Form and content are, in principle, inseparable
Information can, in principle, flow from sender S to receiver R without information flowing from R to S	Information flow requires, in principle, circuits over which to flow (like electric current)

We have a shift from a theory of signal transmission like classical communication theory to a *formal pragmatics*[8] where computers are message processors:

> the systems point of view would [...] principally see computers as communication machines and principally see the material that flows through a computer as documents bearing messages [10, Lecture 3].

While applying his ideas to the design of electronic coordination environments [8], Holt made several examples of disciplines to be imposed on message-handling capabilities within a computer-based information system, like delegation of authority, addressing of messages and their identification and cancellation [16]. Petri [28] compiled a list of such *communication disciplines* classifying the functions of computer as a general medium for strictly organized information flow,

> disciplines of a science of communication yet to be created, and disciplines in the sense of keeping to a set of rules to be followed if communication is to be successful [30].

Understanding these rules becomes essential when the ordinary context of communication is replaced by a computer-based system, and the material carriers of messages are replaced accordingly. For example, an unproblematic notion of 'original' applies to paper-based documents that can be transferred only with difficulty to electronic environments. A discipline of copying in this case is clearly relevant (after all, a copy is defined in opposition to an original), like a discipline of composition, "concerned with determining the structure of documents relative to a material or conceptual carrier" [28], relevant to the legal value of writing.

3 Continuous discrete behavior

The representation of communication relations in a digital context needs a way of representing motion:

> To communicate one must move [...] We will need a theory of motion suited to our ends: the analysis of communication relations. In this connection, the analysis of motion based on the mathematical continuum is not serviceable. It gives us no *systematic* way of relating communication intentions to the mechanics which implement them [7].

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[8] It is formal because its rules are entirely formulated in terms of roles, and it is a pragmatics in the etymological sense, because it concerns communication among actors as action performers. Pragmatics has an obvious bearing on the communication-oriented uses of information technology, and in fact we find ideas from the speech-act theories of Austin, Searle and Habermas at the basis of the 'language/action perspective' of Winograd and Flores and the related coordination programs, and also in the foundational work on information systems by the Scandinavian school of Langefors, Goldkuhl and Lyytinen, among others.

A sense of continuity of motion can be recovered by exploiting the topological aspects of the state/transition structure of digital systems. Petri had observed, circa 1972, that a Petri net with states S, transitions T and flow relation $F \subseteq (S \times T) \cup (T \times S)$ can be regarded as a topological space $X = S \cup T$ by forgetting the direction of flow taking a new relation $A = (F \cup F^{-1}) \cap (S \times T)$ and by defining $U \subseteq X$ to be *open* when $A^{-1}[U] \subseteq U$ [27]. In this topology $\{s\}$ is open for every $s \in S$ and $\{t\}$ is closed for every $t \in T$. In addition, this space has the properties that characterize the *net topologies* [31]:

- Arbitrary unions of closed sets are closed (equivalently, arbitrary intersections of open sets are open);
- Every singleton is either open or closed (the resulting topological space is $T_{\frac{1}{2}}$).[9]

Net topologies were intended originally to be used to define continuous mappings on nets as describing views of a system at different levels of abstractions. The basic insight at the basis of their definition has however a much wider import: by describing the motion of bodies in space (in communication mechanics, the communication between parts) by means of nets, the events and interactions in which the moving bodies are involved are made part of the topological structure of the space:

> one ordinarily imagines that space and time can somehow be structured – i.e., subdivided into nameable entities with topological relations among them *before* describing the actions, interactions, movements, dispositions, etc. of the various distinguishable entities in which one is ultimately interested. We, on the other hand, will see temporal and spatial organization as logically related to the "drama" (or class of dramas) which are to take place in that frame [7, §C].

Instead of spatial regions and their boundaries construed as point-sets, in the topological interpretation of nets we have (open) atomic regions of a state space whose (closed) transitions express the crossing of boundaries, in topological spaces whose points are better expressed by verbs (with different aspectual features) than by nouns. Net topologies allow to introduce notions like continuity, connectedness and boundary in the foundations of a new approach to models of digital phenomena.

> Though the notions 'state' and 'event' are "digital" concepts, ours will not rest on the fiction that events have no real duration – i.e., can be represented by time points in mathematical continuum – nor on the fiction that states have no real extension – i.e., can be associated with space points in a continuum [7].
> The coming about of an objectively verifiable change in anything takes time, and necessarily entails passage through a region of uncertainty. Our

[9] In passing, we remark that closely related topologies have recently been exploited in the definition of the digital line for the purposes of digital image processing [23].

> theory should also not presuppose the fiction of perfect classification schemes [...] Theories based on these fictions cannot account for the effort that must go into achieving reliability in systems [10, pp. 139–40].

On the one hand, these remarks lead to a theory of intransitive indifference relations, of which concurrency is an example, axiomatized by Petri [29, 32] in relation to a finitistic view of continuity as a foundation for measurement. On the other hand, they set the stage for Holt's investigation of motion complying with the needs of communication mechanics, culminating in his unpublished contribution to the May 1981 MIT-IBM conference on Physics of Computation [14]. The basic picture behind his views, recurring through his prolonged meditation on the foundations of state/transition models, is that of a hiker who alternates the crossing of mountains (transitions) with being in valleys (states). One can set up a language describing his motion consisting of elementary statements involving the relations of the hiker with atomic regions of state space and their boundaries (like his being *in* a valley or his being *away* from a boundary). The logic of these statements permits then a purely linguistic interpretation of topological relations between regions of the state space of the hiker, their interiors and boundaries, and ultimately of net topologies. While this work has been left unfinished by Holt, who was aware of its embryonic stage, it offers new technical and philosophical insights into the relation between continuity and discreteness and the possibility of building finite, small models of continuous phenomena that arise at the border between computing and physics. As a conclusion of our outline, we point at this as an interesting direction for future research arising from the work of Petri and Holt.

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References

1. Bateson, M.C.: Our Own Metaphor. A Personal Account of a Conference on the Effects of Conscious Purpose on Human Adaptation. Smithsonian Institution (1972)
2. Burton, D.: Sitting at the Feet of Gurus: The Life and Dance Ethnography of Claire Holt. Xlibris Corporation (2009)
3. Grimes, J.D., Holt, A.W., Ramsey, H.R.: Coordination system technology as the basis for a programming environment. Electrical Communications 57(4), 301–314 (July 1983)
4. Holt, A.W.: General purpose programming systems. Commun. ACM 1(5), 7–9 (May 1958)
5. Holt, A.W.: The personification of computers. Datamation 13(3), 137–138 (1967)
6. Holt, A.W.: Information system theory project: Final report. Tech. Rep. RADC-TR-68–305, NTIS AD 676972, Princeton, N. J.: Applied Data Research, Inc. (September 1968)
7. Holt, A.W.: Communication mechanics. Advanced Course on Operating Systems Principles, Istituto di Elaborazione dell'Informazione, Pisa, Aug. 20–31, 1973 (1973), course material

8. Holt, A.W.: The design of a computer-based communication system. Technical Proposal P-7-002, Massachusetts Computer Associates, Inc., Wakefield, Massachusetts (26 February 1974)
9. Holt, A.W.: Information as a system-relative concept. Technical Report CA-7409-3011, Massachusetts Computer Associates, Inc., Wakefield, Massachusetts (30 September 1974), published in K. Krippendorff (ed.), *Communication and Control in Society*, pages 279–285. Gordon and Breach Science Publishers, 1979.
10. Holt, A.W.: Formal methods in system analysis. In: Shaw, B. (ed.) Computers and the Educated Individual. pp. 135–179. University of Newcastle upon Tyne (1975), http://www.ncl.ac.uk/computing/about/history/seminars/
11. Holt, A.W.: Petri nets and systems analysis. The MIT Conference on Petri-nets and related methods (July 1975), reproduced in [10]
12. Holt, A.W.: Roles and activities. A system for describing systems (30 March 1979), unpublished typescript, 58 pages
13. Holt, A.W.: Computer-based information systems: the views of a quasi-wholist. IFIPS TC-9, Number 9 (September 1980)
14. Holt, A.W.: A mathematical model of continuous discrete beahvior. Technical report, Massachusetts Computer Associates, Inc., Wakefield, Massachusetts (11 November 1980)
15. Holt, A.W.: Coordination technology and Petri nets. In: Rozenberg, G. (ed.) Advances in Petri Nets. Lecture Notes in Computer Science, vol. 222, pp. 278–296. Springer-Verlag (1985)
16. Holt, A.W.: Identification: Generally and in ICECT (12 February 1986), unpublished draft
17. Holt, A.W.: Diplans: A new language for the study and implementation of coordination. ACM Transactions on Office Information Systems 6(2), 109–125 (April 1988)
18. Holt, A.W.: The mechanics of organized human activity (1988), book draft, 100 pages including book overviews
19. Holt, A.W.: Organized Activity and its Support by Computer. Kluwer (1997)
20. Holt, A.W.: Ripensare il mondo. Il computer e i vincoli del sociale. Masson (1998)
21. Holt, A.W., Cardone, F.: An organisational theory of information. In: Falkenberg, E.D., Lyytinen, K., Verrijn-Stuart, A.A. (eds.) Information System Concepts: An Integrated Discipline Emerging. IFIP Conference Proceedings, vol. 164, pp. 77–91. Kluwer (2000)
22. Holt, A.W., Commoner, F.: Events and conditions. In: Dennis, J.B. (ed.) Record of the Project MAC conference on concurrent systems and parallel computation, pp. 3–52. ACM, New York, NY, USA (1970)
23. Khalimsky, E., Kopperman, R., Meyer, P.: Computer graphics and connected topologies on finite ordered sets. Topology and its Applications 36, 1–17 (1990)
24. Licklider, J.C.R., Taylor, R.W.: The computer as a communication device. Science and Technology 76, 21–31 (1968)
25. Meldman, J.A., Holt, A.W.: Petri nets and legal systems. Jurimetrics Journal 12(2), pp. 65–75 (1971)
26. Petri, C.A.: Kommunikation mit Automaten. Ph.D. thesis, Darmstadt Technical University (1962), english Translation as Technical Report RADC-TR-65-377, Vol. 1, Supplement 1, Griffiss Air Force Base, 1966
27. Petri, C.A.: Concepts of net theory. In: Mathematical Foundations of Computer Science: Proceedings of Symposium and Summer School, Strbské Pleso, High Tatras, Czechoslovakia, September 3-8, 1973. pp. 137–146. Mathematical Institute of the Slovak Academy of Sciences (1973)

28. Petri, C.A.: Communication disciplines. In: Shaw, B. (ed.) Computing System Design. pp. 171–183. University of Newcastle upon Tyne (1976), http://www.ncl.ac.uk/computing/about/history/seminars/
29. Petri, C.A.: Modelling as a communication discipline. In: Beilner, H., Gelenbe, E. (eds.) Measuring, Modelling and Evaluating Computer Systems. North-Holland, Amsterdam (1977)
30. Petri, C.A.: Cultural aspects of net theory. Soft Computing 5, 141–145 (2001)
31. Petri, C.A.: Mathematical aspects of net theory. Soft Computing 5, 146–151 (2001)
32. Petri, C.A., Smith, E.: Concurrency and Continuity. In: Rozenberg, G. (ed.) Advances in Petri Nets. Lecture Notes in Computer Science, vol. 266, pp. 273–292. Springer-Verlag, Berlin (1987)
33. Shannon, C.E.: A mathematical theory of communication. The Bell System Technical Journal 27, 379–423 (1948)
34. Smith, E.: Carl Adam Petri. Eine Biographie. Springer-Verlag (2014)